Astronomy

The study of the universe and the objects in it through scientific investigation. Since much of contemporary astronomy uses the laws and methods of physics, the terms "astronomy" and "astrophysics" are usually used interchangeably. However, modern astronomy also uses techniques from many other scientific disciplines, including chemistry, geology, and biology, for which the terms astrochemistry, planetary science, and astrobiology are increasingly used.

The goal of astronomical research is to understand celestial objects and the nature and evolution of the universe by using whatever techniques are appropriate. Astronomers' breadth of knowledge of different types of astronomical objects often gives insights into understanding any given object or physical process.

Scope

Since the advent of spectroscopy in the late nineteenth century, allowing the remote sensing and analysis of the composition and motion of distant objects, the distinction between astronomy and astrophysics has largely evaporated. The view that astronomers study objects in the sky and astrophysicists seek to explain them has been superseded. Some branches of astronomy that are not strictly included in astrophysics involve the study of the motions of the planets and satellites as well as of spacecraft launched from Earth (celestial mechanics) and the measurement of positions and motions of stars (astrometry). However, the extreme astrometric accuracy of the *Hipparcos* space mission in the 1990s gave data that were quickly applied to fundamental distance determinations that are used in assessing the expansion of the universe and other cosmological parameters. So even the traditional fields of astronomy are now so intertwined with astrophysics that no strict distinction is possible. See also: Astrometry; Celestial mechanics

The use of geological knowledge and methods in analyzing close−up observations from spacecraft of planets and their satellites and of comets and asteroids closely links the disciplines of astronomy and planetary science. Indeed, the discovery of planets around distant stars holds for even closer relations in the future. Methods of studying molecules in interstellar clouds involve chemical knowledge. Planetary science and astrochemistry come together with astronomy in the search for life outside the solar system, part of the search for extraterrestrial intelligence (SETI). The National Aeronautics and Space Administration (NASA), the United States space agency, has placed a priority on astrobiology, including the investigation of Mars and the bringing of samples back to Earth from Mars. See also: Asteroid; Comet; Cosmochemistry; Extraterrestrial intelligence; Interstellar matter; Planet; Planetary physics; Solar system

Technologies

Astronomers often lead in employing new technologies, pushing them to the limit in exploring extremely faint signals in various parts of the electromagnetic spectrum. Nearly all astronomical research is now heavily dependent on computers, which control telescopes, help analyze data, make theoretical calculations, display results, provide Internet links for e−mail and the World Wide Web, and allow efficiencies through word processing, image processing, and statistical analysis programs. Even the shapes of telescope mirrors of some of the newest and largest instruments are controlled through computer feedback loops. See also: Digital computer; Image processing

Astronomical imagery is now dominated by light−sensitive silicon chips known as charge−coupled devices (CCDs). In these devices, charge results when a pixel is struck by light, and this charge is then transferred coupled to adjacent pixels in the process of being read out. Charge−coupled devices are approximately 100 times more sensitive than film, and are used at all professional observatories as well as by increasing numbers of students and amateur astronomers. Thus an image or spectrum that formerly took over an hour to record on film can now be recorded in about a minute, with the added benefit over film that the law of reciprocity holds for the data; that is, the strength of the electronic signal produced is directly and linearly proportional to the intensity of the incoming signal. Charge−coupled devices are sensitive throughout the optical and near−infrared portions of the electromagnetic spectrum. Other electronic devices are used in other parts of the spectrum to record incoming signals. See also: Astronomical photography; Charge−coupled devices

Fiber optics are used for a variety of astronomical purposes, including the taking of hundreds of galaxy images simultaneously from the field of view of a telescope and bringing the light to a spectrograph that can produce simultaneous spectra of all the objects. This multiplexing effect can increase the efficiency of sky surveys many times. See also: Fiber−optics imaging

The technology of active optics, in which the shape of a mirror is changed slightly at a high rate (often faster than 1 Hz) to compensate for the blurring of astronomical images caused by the Earth's atmosphere, and of slower adaptive optics was developed largely in secret for military purposes, but has now been released to the public and is being increasingly pursued to eliminate the twinkling of stars. See also: Adaptive optics

Optical telescopes

The opening of the 5−m (200−in.) Hale telescope at the Palomar Observatory on Palomar Mountain, California, in 1948 marked the beginning of a great period of development in optical astronomy. The light−gathering power of this telescope allowed cosmological study that extended most of the way to the beginning of time in the universe. It was joined in the task by several 4−m−class (160−in.) telescopes and by one less successful larger telescope. Apparently, the maximum size of such traditional telescopes had been reached.

In the 1990s, new techniques of telescope making allowed the completion of several telescopes in the 10−m (400−in.) class, twice the diameter and thus four times the collecting area of the Hale telescope. The first to be completed were the twin telescopes at the W. M. Keck Observatory on Mauna Kea in Hawaii. This high site (about 4200 m or 13,800 ft in altitude) with excellent steady air (giving steady images known as good seeing), low amounts of water vapor overhead leading to good infrared transparency, and dark and usually clear skies is the site of several of the largest telescopes in the world. In 1999 the 8−m (320−in.) Subaru ("Pleiades") telescope of the Japanese National Observatory and the 8−m Gemini North telescope of an international consortium were established there. In the Southern Hemisphere, in Chile, better placed to observe various southern objects including the center of the Milky Way Galaxy, the first two 8−m telescopes of the European Southern Observatory's Very Large Telescope (VLT) opened in 1998 and 1999, soon to be joined by two more similar telescopes and several smaller ones. These telescopes, now operated independently, are to be operated together as interferometers when the techniques advance in the first decade of the twenty−first century, as are the Keck telescopes, giving increased resolution. The Gemini South 8−m telescope also operates in Chile. An even larger telescope, though with limited pointing ability in the sky, is operated in Texas for spectroscopic use, and a similar spectroscopic telescope is planned for South Africa.

The large telescopes have proven useful in taking spectra of the optical counterparts of gamma−ray bursts, proving that they are very far away; and in analyzing the distances to faraway galaxies and in measuring the redshifts of their spectra, leading to the current cosmological models of the expansion of the universe and the tentative conclusion that the rate of expansion is accelerating. See also: Cosmology; Hubble constant; Telescope

Telescopes in space

The 1990s saw the thorough use of the vantage points of space for astronomical observation, exemplified by NASA's series of Great Observatories. In 1991 the *Compton Gamma−Ray Observatory* was launched, and in the following years mapped about one gamma−ray burst per day in addition to many other objects and events. The Hubble Space Telescope was launched in 1990 to study the ultraviolet and visible parts of the spectrum. Its repair in 1993, with secondary mirrors compensating for a focusing problem with the main mirror, brought it to full working order, and a 1996 upgrade included an improved two−dimensional spectrograph and infrared capability. The *Chandra X−Ray Observatory*, launched in 1999, provides high−resolution x−ray images, and is the same size and scope as Hubble. It studies various types of celestial objects and processes, such as black holes of stellar and galactic sizes. The *Space Infrared Telescope Facility* is to be the fourth of this series of Great Observatories. See also: Black hole; Gamma−ray astronomy; Infrared astronomy; X−ray astronomy; X−ray telescope

Smaller spacecraft have also made valuable contributions. The *Cosmic Background Explorer* (*COBE*) in the early 1990s mapped the cosmic background radiation and provided important clues to the origin of the universe and its large−scale structure. NASA's Explorer series continues with a variety of mid−sized spacecraft. The European Space Agency's *Solar and Heliospheric Observatory* (*SOHO*) and *Infrared Space Observatory* (*ISO*) have also sent back valuable observations. See also: Astrophysics, high−energy; Cosmic background radiation; Satellite (astronomy); Sun

Telescopes across the spectrum

The atmosphere blocks most of the electromagnetic spectrum from reaching the Earth's surface, leaving windows of transparency mostly in the optical and radio parts of the spectrum. Radio astronomers have made the most of their window of transparency with such telescopes as the 100−m (328−ft) fully steerable telescope outside Bonn, Germany; the 330−m (1083−ft) Arecibo dish in Puerto Rico, in which the secondary mirror can be moved over a spherical bowl covered with mesh to give some limited tracking ability; and the precise, large Green Bank telescope in West Virginia, opened in

1990 to allow studies of interstellar molecules. Radio astronomers pioneered the use of interferometry, taking advantage of the long wavelengths at which they observe. The Very Large Array of radio telescopes of the National Radio Astronomy Observatory extends about 25 km (15 mi) over a plain in New Mexico, synthesizing the aperture to provide the resolution (though not the collecting area) of a single telescope of that size. The Very Long Baseline Array uses a dedicated set of telescopes on various sites across the globe to synthesize a telescope the size of the Earth. See also: Radio astronomy; Radio telescope

The ozone layer and other constituents of the atmosphere block the shortest wavelengths from penetrating to the Earth's surface, so observations of gamma rays, x−rays, and most of the ultraviolet region require telescopes in space. Similarly, water vapor blocks most of the infrared, allowing only a few windows of transparency, and observations from balloons and, to go higher, from spacecraft are necessary to cover the whole infrared spectrum. See also: Ozone; Ultraviolet astronomy

Spectroscopy

Much of astronomy involves breaking down the incoming celestial radiation into its component wavelengths, a process known as spectroscopy. The brighter the object, the finer the spectroscopic resolution in wavelength that can be obtained. Spectroscopic studies can reveal the temperature of an object, the identity and proportions of its chemical elements, and the velocities of its constituents toward and away from the Earth. Light from the Sun and other objects is sometimes polarized, and studies of such polarization can tell about the magnetic fields present or about scattering processes. See also: Astronomical spectroscopy; Polarimetry

Non−electromagnetic−radiation telescopes

Though most of what astronomers study is electromagnetic radiation in its various forms, some particles do arrive at the Earth. The expansive definition of a telescope includes anything used in astronomy to observe the sky. Several neutrino telescopes have been used to detect neutrinos from the Sun and, in one instance, from a supernova. The original neutrino telescope was a large tank of cleaning fluid based in a mine far underground. Subsequent neutrino telescopes are tanks of gallium and even larger tanks of purified water, in which interactions with neutrinos have detectable consequences. See also: Neutrino; Solar neutrinos

Cosmic rays are particles from the Sun and from more distant objects in space. These primary cosmic rays interact with particles in the Earth's atmosphere to make secondary cosmic rays, and the pace of observation of these secondary cosmic rays as well as the few primary cosmic rays that reach the Earth is increasing. See also: Cosmic rays

Gravitational waves are a consequence of Einstein's general theory of relativity, and their existence was verified indirectly by careful study of the period of a binary pulsar. A pair of interferometers are being built on Earth to attempt direct detection of such gravitational waves, which should result from such distant events as the merger of two neutron stars.

Theory and computation

Theoretical calculations of the nature of astronomical objects or processes are known as theoretical astrophysics. Theoretical astrophysists analyze the evolution of stars, analyze the solar wind of expanding plasma around the Sun, trace the explosion phase of supernovae, calculate the distribution of sizes of structures formed in the early eons of the universe, or analyze the formation of the light elements in the first minutes after the big bang. Cosmological calculations use Einstein's general theory of relativity. See also: Big bang theory; Plasma (physics); Relativity; Star; Stellar evolution; Supernova

The availability of supercomputers, powerful and fast computers capable of handling large amounts of data, has led to three−dimensional simulations of, for example, the effects of varying amounts of cold dark matter (such as undiscovered types of subatomic particles) and hot dark matter (such as neutrinos) in the formation of large−scale structure in the early universe. Such dark matter apparently exceeds the amount of matter detectable through more traditional methods of observation. Even this dark matter may be exceeded by energy implied by the existence of the cosmological constant, energy transformable into mass in an amount calculable with Einstein's equation. Such a cosmological constant is being seriously considered based on analysis of the recession of distant supernovae. See also: Simulation; Supercomputer; Universe

Models of the oscillations detectable on the Sun's surface through long−time−series observations made on the ground from the Global Oscillation Network Group (GONG) or from space with instruments on the *Solar and Heliospheric*

Observatory (*SOHO*) are used to improve understanding of the solar interior, a process known as helioseismology. See also: Helioseismology

Experimental astrophysics

Laboratory astrophysics involves the measurement of basic parameters that are used in calculations of physical or chemical processes relevant to astronomy. Though the Sun and stars as well as interstellar space are excellent laboratories for studying processes at high temperature or in vacuums unobtainable on Earth, sometimes fundamental parameters such as cross sections of atomic and molecular collisional excitation and ionization can be measured in laboratories on Earth. See also: Atomic structure and spectra; Molecular structure and spectra

Historical astronomy

Studying astronomy's history provides data for comparison with the present. For example, the paths of solar eclipses from hundreds or thousands of years ago can be analyzed to study the rate of rotation of the Earth and the relation between astronomical timekeeping and timekeeping by atomic methods, leading to an improved understanding of processes inside the Earth. See also: Archeoastronomy; Day; Earth rotation and orbital motion; Eclipse; Time; Year

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How to cite this article

Suggested citation for this article:

Jay M. Pasachoff, "Astronomy", in AccessScience@McGraw−Hill, http://www.accessscience.com, DOI 10.1036/1097−8542.057900, last modified: April 16, 2002.

For Further Study

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